ACTIVE RADIO FREQUENCY CAVITY AMPLIFIER

PRIORITY

This application claims priority to an application entitled "ACTIVE RADIO

5   FREQUENCY CAVITY AMPLIFIER" filed in the United States Patent and Trademark Office

on December 12, 2000 and assigned Serial No. 60/255,276, the contents of which are hereby

incorporated by reference.

BACKGROUND OF THE INVENTION

10   **1. Field of the Invention**

This invention relates to radio frequency (RF) electromagnetic (EM) field resonant

cavities, and more particularly to such cavities in which high RF power output is to be achieved.

2. Description of the Related Art

It is known to generate high frequency EM fields in a cavity for the purpose, e.g., of

15   accelerating a charged particle beam in a radio frequency (RF) accelerator, such as a linear

accelerator. In a typical construction of a linear accelerator, RF power is provided by a number

of vacuum tube amplifiers operating at a high voltage (tens of kilovolts or higher) and the

amplified RF power is transmitted from the RF tubes to the cavity by means of a coaxial cable,

or the like, to form an oscillating EM field inside the cavity. One common type of linear

20   accelerator (linac), the drift tube linac (DTL), has a series of drift tubes which are arranged

within the cavity so that the particles are accelerated by the electric field to form the desired

particle beam.

There are a number of applications or potential applications for which relatively light-

weight and easily transportable RF cavities or linacs would be desirable. These applications include earth-orbit based applications; decentralized, on-demand production of medical isotopes; and high-power RF amplifiers, among others. However, the substantial weight and size of the necessary RF tubes, high voltage power supply and power conditioning equipment, and

5   associated components, has been a significant deterrent to use of RF cavities or linacs for these purposes.

One proposed solution to overcome the disadvantages of the above-mentioned RF cavities is shown and described in U.S. Patent No. 5,497,050 issued to Bernard R. Cheo on March 5, 1996. FIG. 4 of U.S. Patent No. 5,497,050, reproduced in this application as FIG. 1,

10   shows an RF cavity 110 defined by a wall 112, which has a conductive inner surface 114. The wall 112 is divided into upper and lower cylindrical sections 120 and 122 and installed between the sections is an annular array 124 of solid state power amplifier modules 126. Each module 126 has an input terminal which is connected to a source of a relatively low power RF driving signal. A positive d.c. terminal 140 is connected to the upper section 120 at an outer surface, and

15   similarly, a negative d.c. terminal 146 is connected to the lower section 122 via a quarter-wavelength choke connection. When used as an amplifier, the RF cavity 110 includes a waveguide 160, or alternatively, a coaxial cable output connector, for taking out high power EM waves from the cavity 110.

In operation, the RF driving input power applied to the terminals of the amplifier

20   modules 126 is at a frequency that corresponds to that of the desired resonant mode of cavity 110. Under control of the input drive amplifier modules 126 induce a large RF current, with a peak amplitude on the order of several kiloamps, to flow at inner surface 114 of wall 112, so that the desired EM field amplitude is established. Due to skin effect, this current flows along the

inside surface of the cavity wall to a depth on the order of few microns. The d.c. current which passes through the modules flows through the bulk of wall 112. The amplifier modules 126, which are low impedance devices, operate at high-current/low-voltage, while a particle beam generated along an axis of cavity 110 is at high-voltage/low-current, representing a high impedance load. Thus, the RF cavity 110 disclosed serves at once as a power combiner and a matching transformer for the amplifier modules 126.

Due to its construction, a minimal amount of packaging is required within the modules 126, because the wall 112 of cavity 110 serves as a heat sink for the transistors. The system's total cooling budget is not increased, while most of the packaging, which makes up the heaviest part of a transistor RF power system, is eliminated. Additionally, since the vacuum tubes required for conventional RF linear accelerators are not required to be provided with accelerator cavity 110, the break-down problems of high voltage equipment in earth orbit are eliminated. Further, the power supply of the cavity 110 avoids the RF power transmission loss of conventional accelerators, thereby achieving higher efficiency.

While the cavity disclosed in U.S. Patent 5,497,050 is highly effective for use as a linear accelerator, it lacks the structure for efficient operation as an amplifier. First, the cavity disclosed only shows a waveguide as the cavity's output port with no mention of an input port for receiving the RF power which is to be amplified. Second, for any radio frequency device involving a resonant cavity, it is necessary that frequency tuning can be performed in order that it can operate properly and at the desired frequency. The prior art RF cavity disclosed by U.S. Patent No. 5,497,050 neither addresses nor shows any means by which tuning can be achieved when acting as an amplifier.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a high-power RF cavity that can easily be transformed into an efficient high-power amplifier.

It is another object of the present invention to provide a high-power amplifier with

5 discrete input and output ports.

It is a further object of the invention to provide a high-power amplifier with frequency tuning capabilities.

According to the present invention, the foregoing objects are met by the provision of an active radio frequency cavity amplifier (ARFCA). The ARFCA includes a housing defining two

10 independently tunable resonant cavities. Each cavity is generally cylindrical and includes conductive walls. Conductive structures in a first cavity, i.e., an input cavity, couple an RF field within the input cavity to input leads of a plurality of power transistors formed in an annular array. Similarly, conductive structures in a second cavity, i.e., an output cavity, couple an RF field within the output cavity to output leads of the plurality of power transistors.

15 A plunger assembly is provided for the input cavity for coupling low RF power from a source into the input cavity. A plunger assembly is also provided for the output cavity for coupling the amplified RF power out to a load. The plunger assembly of each cavity further serves as a mechanism for tuning the cavities to resonate at the desired operating frequency.

The ARFCA in accordance with the present invention is a relatively low weight device,

20 using a low voltage DC power source for the RF power transistors. The input caivty functions as a power distributor and matching transformer to the input of a large number of RF power transistors. The output cavity serves as the power combiner and the matching transformer from

the output of the same transistors. The walls of the cavities can serve as a heat sink. High combining efficiency is achieved.

According to an aspect of the invention, the combination of transistors in the ARFCA is accomplished in one step, and therefore, there is no accumulation of losses and phase errors

5 through stages as in conventional cascaded multiple stage approaches for combining large number of devices. Furthermore, each cavity is inherently less lossy than the stripline structures used in conventional approaches, and as a result, the efficiency and gain of the ARFCA can approach that of the individual transistors used.

According to another aspect of the invention, the ARFCA requires no vacuum and has no

10 complex electrodes, circuits or windows, and therefore, various parts of the structure can be mass-produced by standard CNC machines. Additionally, since combining and impedance matching is accomplished with the cavities, the ARFCA requires no other discrete passive electronic components in its RF circuitry, and as a result, the ARFCA's reliability is increased.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

The above and other objects, features and advantages of the present invention will become apparent from the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view of a prior art radio frequency cavity;

20 FIG. 2 is a perspective view, partially broken away, of an active radio frequency cavity amplifier (ARFCA) in accordance with the present invention;

FIG. 3 is a top plan view of a generic transistor package used in the ARFCA of FIG. 2;

FIG. 4A is a partial schematic diagram of the ARFCA as seen along line 4A-4A of FIG.2;

FIG. 4B is an enlarged partial view of FIG. 4A illustrating the coupling of the conducting rods of the input/output cavities of the ARFCA to a transistor; and

FIG. 4C is a side elevational view of an upper coupling mechanism in accordance with the present invention.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A preferred embodiment of the present invention will be described hereinbleow with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail since they would obscure the invention in unnecessary 10 detail.

Referring to the FIG. 2, an active radio frequency cavity amplifier (ARFCA) of the present invention is designated by the reference numeral 10. The ARFCA includes two independently tunable resonant cavities 12, 14. The cavities 12, 14 are mated together by a center plate 16 on which a plurality of transistors 18 are mounted. The cavity 12 is coupled to 15 input leads of the plurality of transistors 18, and thus, is referred to as the input cavity. Similarly, the cavity 14 is coupled to output leads of the plurality of transistors 18 and likewise is referred to as the output cavity.

As illustrated by FIG. 2, the two cavities 12,14 are substantially symmetrically identical for maintaining a resonant RF field therein, except they generally require different matching due 20 to the difference of impedance matching needed for the transistor input and output. For simplicity purposes, only the structure of the input cavity 12 is described in detail hereinbelow, since the structure of the output cavity 14 is similar to the structure of the input cavity 12.

The first cavity 12 is defined by a generally cylindrical housing 20 having an open end 22, a closed end 24, and the center plate 16. The cavity 12 is bound by a first cylindrical wall 26 within the cylindrical housing 20. A second cylindrical wall 28 formed with an annular cavity 30 defined by housing 20 surrounds wall 26 to act as RF choke to prevent the RF input to the

5   transistors 18 from being short-circuited during operation. It is contemplated that other types of structures for the second cylindrical wall 28 can be used to act as the RF choke, such as having the second cylindrical wall 28 extend outward from the wall 26 without being bent to vertical.

The lower portion of wall 28 includes an annular rim 32 for connecting the open end 22 of housing 20 to the center plate 16. The cylindrical housing 20 is constructed from conductive

10   materials, such as copper or aluminum, or any other conductive or superconductive materials known in the art.

The closed end 24 of housing 20 defines an aperture 34 for placement of a plunger assembly 36 therein. The plunger assembly 36 includes a conducting circular disc 38, a dielectric disc 40, and a conducting cylindrical plunger 42 which collectively acts as a coupling capacitor.

15   With reference to FIG. 4A, there is shown a schematic block diagram of the plunger assembly 36. The plunger assembly 36 further includes a coaxial section 41 formed by channel 44 and center conductor 46 including a matching section 48 for inputting and/or outputting RF power, e.g., the low input RF power and the amplified input RF power, to and from the active radio frequency amplifier 10. That is, structures 38, 40, 42, and 46 of the first or input cavity 12

20   couple low RF power from the external source into the first cavity 12, and the same structures of the second or output cavity 14 couple the amplified RF power out to the load.

Each plunger assembly 36 is movable within its respective aperture 34. The plunger assemblies 36 are moved manually or via threaded screws until the desired resonant frequency is

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reached. It is contemplated that the amount of movement into the apertures 34 of each plunger

assembly 36 is approximately known in advance for the desired operating frequency.

The center plate 16 is generally circular and includes an upper annular plate 50 for

defining the boundary of the first cavity 12 and a lower annular plate 52 for defining the

5   boundary of the second cavity 14. The upper and lower annular plates 50, 52 are joined by a

circular structure 54 upon which are disposed the plurality of transistors 18 as a circular array.

FIG. 3 is a top plan view of a generic transistor package preferably used for the plurality

of transistors 18. The table below identifies, with respect to the particular transistor type, its two

leads 18x and 18y, and its mounting flange 18F, which is electrically common to both input and

10   output, and also conducts the heat generated internally by the transistor 18 to the walls of cavities

12, 14, which serve as a heat sink.

	BJT: COMMON BASE	BJT: COMMON EMITTER	FET
18x	COLLECTOR	COLLECTOR	DRAIN
18y	EMITTER	BASE	GATE
18F	BASE	EMITTER	SOURCE

In operation, d.c. power is applied to the transistor leads 18x and 18y through a normal

wire lead 60a (FIGS. 1and 4C) via a conducting rod 62a. Since the d.c. power is applied to each

15   of the plurality of transistors 18, it is possible to use elements, such as ferrite beads (not shown),

in the drain or collector power supply circuit of each transistor 18 to ensure its stable operation.

Bias voltages applied to each input lead 18x can be adjusted independently to provide a

means to deal with the problems caused by the lack of uniformity among the transistors used.

The housing 20 and the center plate 16 are at d.c. ground potential to ensure safety in the

operation of the ARFCA 10. As shown in FIG. 4C, contact is maintained between the conducting

rod 62a and a respective transistor input lead 18x by pressure exerted on the rod 62a by an upper

coupling mechanism 55a having a screw 64a, spring 66a, and an insulating section 68a. It is

noted that an upper coupling mechanism 55a is provided for each of the plurality of transistors

5   18. If so desire, contacts may also be maintained by soldering the rods 62a,b to the transistor

leads 18x, y.

       Similarly, pressure is exerted on a conducting rod 62b by a lower coupling mechanism

55b having a similar structure as the upper coupling mechanism 55b. That is, lower coupling

mechanism 55b includes a conducting rod 62b, which is in contact with a respective transistor

10   output lead 18y, by a coaxial coupling capacitor formed by the conducting rod 62b, a dielectric

sleeve 70b, and an outer conductor 72b through a gap "g" at the base of the output cavity 14 to

couple the output RF power of each of the transistor 18 to the output cavity 14 via the conducting

rod 62b. The combined output RF power from all the transistors is greater than the input RF

power from the source, since each of the plurality of transistors 18 amplifies the input RF power.

15   It is noted that a lower coupling mechanism 55b is provided for each of the plurality of

transistors 18.

       In other words, at each transistor 18, structures 62a, 70a and 72a or the coaxial coupling

capacitor of the input cavity 12 couple the RF field in the input cavity 12 to the transistor's input

leads 18x, and structures 62b, 70b and 72b or the coaxial coupling capacitor of the output cavity

20   14 couple the RF field in the output cavity 14 to the transistor's output leads 18y. In low

frequency applications, a lumped chip capacitor may be used instead of the coaxial coupling

capacitor. The RF field in the desired cavity mode, e.g., the TM_{010} mode, is coupled out from the

cavity 14 to the load via the components of the coupling capacitor of the plunger assembly 36 of

the output cavity 14. These components include the conducting circular disc 38, the dielectric

disc 40, and the bottom face of the conducting cylindrical plunger 42.

As stated above, each plunger assembly 36 functions to tune the resonant frequency of its

respective cavity by varying the depth of penetration of the plunger 42 into the respective cavity.

5   The depth can be varied manually or automatically by providing an automated control

mechanism. The coaxial section 41 formed by channel 44 of the plunger assembly 36, and the

center conductor 46, including the matching section 48, then couples the amplified RF power out

through a standard coaxial connector.

At the input side, the direction of flow of the RF power is reversed from that of the output

10   side: from the input connector mounted on the plunger assembly 36 through the coaxial channel

and the coupling capacitor, the RF power reaches the input leads 18x of the transistors 18

through the gap "g" at the base of the input cavity 12 and the components 62a, 70a and 72a of

the coaxial coupling capacitor. The components of the output cavity 14 which correspond to

those of the input cavity 14 are similar in structure and serve similar purposes.

15   It should be understood that most of the conductive components of the ARFCA are in

good thermal contact with one another, and hence, thermally become one unit body. Cooling fins

may be installed for effective forced air cooling. Alternatively, liquid cooling can be readily

implemented by creating coolant channels in the center plate or elsewhere in the conductive

housing.

20   While the invention has been shown and described with reference to a certain preferred

embodiment thereof, it will be understood by those skilled in the art that various changes in form

and details may be made therein without departing from the spirit and scope of the invention as

defined by the appended claims.